Appendix B – Lessons Learned

The issues have been grouped by the following categories:

Communication	(Issues 1 through 5)
Emergency Management	(Issues 6 through 17)
Water Management	(Issues 18 through 27)

The issues are not in any particular order within the category.

Category: Communication

1. Issue: Improve integration with the United States Geological Survey.

What was planned?

-Maintain communication and cooperation between the Corps, National Weather Service (NWS) and United States Geological Survey (USGS) during a flood event.

What actually happened?

-The Kentucky and Tennessee USGS Water Science Centers (WSCs) were under utilized by LRD, LRN and the NWS during the event. The USGS wanted to be better integrated with the LRD, LRN and NWS response in the midst of the event. During the event, USGS deployed personnel in the field to take flow measures at key locations, improve stage-discharge rating curves and repair equipment. They could have also provided real-time observations.
-The USGS could not assist in maintaining operation of critical gages during the event since they were not aware of what gages were critical.
-The USGS could not insure the critical gage readings were obtained during the event since they were not aware of what gages are critical or what the critical flood levels are.
-The NWS Ohio River Forecast Center (OHRFC) did request high water measurements on Sunday morning for the Harpeth River and utilized the information received in its river modeling.

Why did it happen?

-Due to budget considerations, LRN withdrew from the USGS Cooperative Gaging Program approximately 5 years ago and ended its direct working relationship with the USGS.
-The LRD, LRN and the NWS did not consider involving the USGS in the LRD led conference calls.
-The USGS did not contact the LRN WM or the NWSWFO to see if they needed assistance until after the crest and the river began to recede.
-Critical gages and gage ratings have not been communicated to the USGS. LRN WM has contracted gage maintenance during the last five years. The gage rating curves have not been updated during this period.
-Past budget decisions and priorities may have impacted gage maintenance.

How can we do it better and who has the lead to fix it?

-District Water Management offices will invite USGS to participate in conference calls.

-LRN has established a transition plan to enter the USGS Cooperative Gaging Program.

-LRD WM will evaluate the use of NWS Chat.

-LRN and the NWS OHRFC and the NWS Nashville WFO will provide the USGS with a listing of critical gages such that they can assist in maintaining their operation during flood events.

-The local NWS WFOs will provide the Kentucky and Tennessee USGS a listing of all critical flood stages and major flood levels. Manual readings (stage and flow) for sites where major flooding is occurring, where gages are out (overtopped, etc.) or where readings are above current ratings are valuable to the NWS. The USGS will be able to monitor these locations during flood events.

-LRN WM will evaluate having high level staff gages at various locations that can be used during record flood events.

-USGS, NWS, and the Division Water Management offices will conduct annual office visits. Participation will also continue in the Ohio Valley Tri-agency meetings. Many offices participate annually, but will need to require attendance by all affected offices to ensure important topics are discussed.

Category: Communication

2. Issue: Improve internal communications before and during potential flood events.

What was planned?

-Provide communication regarding potential for flooding.

What actually happened?

-On Wednesday, April 28th, LRD noted the high NWS Quantitative Precipitation Forecast (QPF) and began monitoring the storm. The Early Morning Weather and River Update issued that day discussed the rainfall potential and noted that reservoir releases would increase over the next several days in response to the forecast rainfall.

-On Thursday, April 29th, the NWS Quantitative Precipitation Forecast QPF continued to show 3-6" of rainfall and LRD issued a Flood Potential Update apprising the senior leadership, the LRN Commander, Emergency Operations and Public Affairs of the upcoming rainfall event. The LRN Commander responded with LRN measures being taken in response to the QPF. This email did not get immediate attention by LRD staff resulting in slower communication up the chain of command regarding the potential severity of the event.

-LRD WM only issues the Flood Potential Updates when there is a significant event forecasted.

-LRD WM and the NWS OHRFC began coordinating the flood potential on April 28th.

Why did it happen?

-The emails were not read, perhaps from an overload of emails in mailboxes.

-A trigger does not exist at the Division staff level to activate the staff into an emergency mode. Note that this would be the Crisis Action Team according to the LRD Emergency Operations Center's (EOC's) standard operating procedures.

How can we do it better and who has the lead to fix it?

-LRD WM will add the District EOCs to its distribution list for the Early Morning Weather and River Update.

-The Division office will utilize telephonic notification for passing critical notifications. The Division Office will consider adoption of an Automated Notification System (ANS).

-The Deputy Division Commander will develop a trigger for significant events that would convene an emergency meeting of key staff. The staff would then have the opportunity to:

1. Receive briefing on the developing situation to ensure common understanding.
2. Allow the impacted district(s) to request support and identify resources needed.
3. Have each staff officer explain what they are doing, what they plan to do to support, and any issues. This ensures all resources and support are brought to bear on the situation as well as to synchronize efforts.
4. Allow the commander an opportunity to give intent and guidance to everyone.

-An alternate trigger may be developed that activates a Division Team for coordination across functions. The Team should include as a minimum, the Deputy Commander, Water Management, Emergency Management, Public Affairs Office (PAO), Counsel, Operations, and Dam Safety.

Category: Communication
3. Issue: Provide redundant communication systems.

What was planned?
-Communicate with project personnel concerning project release updates during the flood event.

What actually happened?
-Internet outage occurred due to a Verizon communication line break.
-The network outage that occurred on May 2 (Sunday) during a critical period eliminated the electronic transmission of project data to the Water Management office. The only source of project data was via telephone conversations with the operators located at the projects.
-The outage impaired the ability of the Water Management personnel to quickly analyze and respond to changing conditions.

Why did it happen?
-The hydropower operators manually enter project data into a spreadsheet system that is subsequently transferred via the network to the District Office where it automatically updates both the water control database and the web-site. Data is also transmitted via satellite to a local downlink station located at J. Percy Priest project office. The data from the local downlink is also transmitted to the District via the Internet. When the network went down these processes became inoperable.

How can we do it better and who has the lead to fix it?
-LRN WM will build redundancy into the project data reporting system so a single point of failure in the network will not compromise information exchange.
–Air cards and laptops have been secured for the Water Management office and for the manned powerhouses to facilitate information exchange.
-Satellite phones are being secured for the Water Management office and the manned powerhouses as a backup for landlines and cell phones, both of which are prone to failure during certain natural disasters.

Category: Communication
4. Issue: Improving risk communication.

What was planned?
-Provide effective risk communication to the public.

What actually happened?
-LRN WM fielded several questions from the public during the event regarding the physical extent of the areas that have the potential to be flooded based on the NWS stage forecasts. There is also a misconception of which projects provide flood control benefits. This is particularly true for the Nashville area, downstream of Old Hickory Dam where the public associates the upstream dam with flood protection rather than for navigation.
-LRN WM personnel fielded numerous phone calls from the public during the flood event requesting information on the extent of flooding expected in their area. With minimum personnel available the calls diverted staff time away from developing and implementing reservoir system operation plans.

Why did it happen?
-NWS forecast are provided in terms of river stage with some associated reference points/impacts.
-This event occurred over the weekend, when limited personnel were in the District office to handle communication with the public.
-A common public misperception is that all navigation projects hold back floodwaters just like flood risk management projects.
-NWS is responsible for providing the public flood forecast information; however, most people appear to associate that responsibility to the Corps.

How can we do it better and who has the lead to fix it?
-The Corps (LRN-EC-H) (Nashville District Corps of Engineers, Hydraulics and Hydrology Branch) and the NWS Nashville WFO will develop an interagency process that relays crest stage information in a manner that gives the general public more knowledge as to the effect on an individual, i.e. what does 51.5' Nashville river stage mean for Pennington Bend?
-Inundation maps available to the public would be beneficial. Model-based GIS inundation map products could be developed for a range of river stage values. NOAA, USGS and Corps are developing an Integrated Water Resources Science and Services (IWRSS) Memorandum of Understanding (MOU) to create a technical team to evaluate inundation maps as part of the data synchronization team. Options are being explored for publishing these maps in a forum that would enhance the protection of public health and safety.
-The LRN and LRD Public Affairs offices will develop operating procedures that ensure all public affairs communication functions are adequately covered, such as handling media inquiries, media interviews, message development, fielding calls from the public and other essential strategic communication (STRATCOM) functions.
-Affected Corps' Districts will have a small number of people dedicated to answering telephone calls in order to give consistent information to callers.

-LRN will increase risk communication discussions with the public to improve awareness of the operations of Corps' project and the flooding risks.
-Silver Jackets[1] can assist in education of the public through its members. The Silver Jackets can also serve to improve communications between all stakeholders for flood risk management.

[1] **The Silver Jackets program is a program through which the US Army Corps of Engineers, Federal Emergency Management Agency, State EMA, and State Department of Natural Resources, and other Federal and State agencies collaborate to develop and implement solutions to State natural hazard priorities. The Silver Jackets Program provides a formal and consistent strategy for an interagency approach to planning and implementing measures to reduce the risks associated with natural hazards. The program's primary goals are to leverage information and resources, improve public risk communication through a united effort, and create a mechanism to collaboratively solve issues and implement initiatives.**

Category: Communication
5. Issue: Improve District recall of personnel.

What was planned?
-Assure that appropriate District personnel were on hand to provide assistance during the event.

What actually happened?
-The LRN District office was minimally staffed as the event developed on Saturday.
-Many of the District's personnel were being impacted by the flood. The extreme weather made it difficult and in some cases impossible for personnel to return to duty at the District headquarters. The staff at the District headquarters had to divide their time between regular duties and answering public inquiries.
-A 100% accountability procedure (phone tree) was implemented Sunday to establish accountability of personnel and to check on their status.
-The District recalled critical personnel to duty but there was no clear communication of who was considered "non-essential" personnel versus "essential" personnel.

Why did it happen?
-The event unfolded over a weekend; hence, the office was not staffed as it would have been on a weekday.
-LRN office closed on Monday as well. Only essential personnel asked to report.
- The flood directly impacted many staff members who experienced great obstacles in travel around the city.

How can we do it better and who has the lead to fix it?
-LRN will evaluate, update and revise their recall processes and system. The Division Office will consider adoption of an Automated Notification System (ANS) to assist the District Offices with their recall process.

Category: Emergency Management

6. Issue: Sustain communications between LRN Emergency Management and the Tennessee Emergency Management Agency.

What was planned?

-Effective communications.

What actually happened?

-A line of communication between the Tennessee Emergency Management Agency (EMA) and the LRN EOC was established.
-The EOC personnel felt that they would be more effective if they had a data sheet from the subject matter experts dealing with each event so that the EOC can speak accurately about relative topics.
-Communication with the State of Tennessee Emergency Management Agency went very well. The Emergency Management Liaison embedded in the State EOC, was able to coordinate delivery of supplies within hours of being requested: and was able to supply them with information concerning PL 84-99.
-LRN conducted numerous conference calls
-The LRN EOC has three assigned personnel. One person was assigned to the State EOC. The remaining two personnel maintained EOC operations at the District headquarters and provided technical assistance to other local agencies.
-Effective communication with the EM in Memphis District was maintained throughout the event.

Why did it happen?

- The LRN EOC has well established and understood standard operating procedures.

How can we do it better and who has the lead to fix it?

-LRN EM will work with LRN Engineering and Construction Division to establish a standard data sheet from subject matter experts so that the EOC personnel can speak accurately about relevant topics.
-The LRN EM Office will provide basic emergency management training for District personnel to ensure all personnel understand their role during response operations.

Category: Emergency Management
7. Issue: Sustain Emergency Management Operations.

What was planned?
-The LRN EM office provided timely response efforts in accordance to Public Law 84-99 (provides the authority to conduct emergency preparation and response activities for a flood fight) and Public Law 93-288, Robert T. Stafford Relief and Emergency Assistance Act

What actually happened?
-LRN initiated its All Hazard Plan (Draft) during this event. The plan provided an effective framework for responding to the event.
-LRN EM established a liaison with the Tennessee State EM Operations beginning May 2, 2010.
-LRN followed the All Hazard Plan and LRD EM SOP during the event.
-Under Public Law 84-99 LRN provided equipment, Technical Assistance and sandbags to the state or local governments.
-The District smoothly transitioned to support under Public Law 93-288 Robert T. Stafford Relief and Emergency Assistance Act. Emergency Support Function (ESF) # 3 support was established on May 5, 2010. A Team Leader and LRN EM office continued to provide support to FEMA at the State EMA and Joint Field Office.

Why did it happen?
-LRN EM Office has well established, rehearsed and coordinated procedures.

How can we do it better and who has the lead to fix it?
-LRN EM will distribute and store sandbags throughout the Tennessee and Cumberland River Basins to ensure faster response to sandbag requests.
-The District will augment the LRN EM Liaison with the appropriate subject matter expert from the District (or externally augmented) who is well versed in the type of event occurring.

Category: Emergency Management
8. Issue: Efficient use of ENGLink.

What was planned?
-Effective usage of ENGLink.[2]

What actually happened?
-The LRN EOC specialist was very adaptable and eager to learn some new techniques as the event progressed.
-EOC members need to have all rights as a Strike Team member.
-Enlisted the help of a LRN Strike Team member (Navigation Branch) to assist in the preparation of the Response Organization Document and the tasker process. This helped EOC personnel greatly by allowing the smooth transition of taskers.

Why did it happen?
-Standard Operating Procedure.

How can we do it better and who has the lead to fix it?
- LRD EM will continue to provide training so that EOC personnel can perform their duties in ENGLink more efficiently.

[2] **ENGlink is the software program use by USACE to manage information, execution and personnel in response to an event. It also contains a database of all Corps personnel to document physical status, training and essential personnel data.**

Category: Emergency Management
9. Issue: Sustain pre-event coordination.

What was planned?
-In accordance with proven Business Line practices LRD-EM coordinated calls with LRD WM and the potentially impacted Districts (LRL/LRN).

What actually happened?
-LRD EM remained in close coordination with both LRL and LRN EM a week in advance of the May 1, 2010 flood event. The EM offices had been working response to storms in the Midwest the week prior. On April 28th the LRD WM office sent an update that indicated heavy precipitation west of the Ohio River Basin. EM and WM offices have a long standing practice of sharing information on a routine basis, anticipating potential impacts, and posturing for a timely effective response.
-The LRD EM office maintained coordination with the USACE Operations Center and other Major Subordinate Command through the use of daily conference call that started on April 28. Water Management participated in these coordination calls and briefs.
-Coordinated with HQUSACE and identification of appropriate ESF #3 personnel to staff key Command and Control positions at FEMA IV and Incident Management Assistance Team (IMAT) prior to the actual May 1, 2010 flood event.
-Temporary duty cancelled on April 30, 2010 for LRD-EM and MVM-EM scheduled to attend ESF #3 ATL workshop the week of May 2, 2010 in anticipation of the potential flooding.
-Ironically, LRD and representatives from our seven District EM offices participated in a Response Mission Workshop (April 21-22, 2010), coordinated by LRN-EM, with TEMA where each of our Districts presented Mission Planning Response Teams specific operational briefs. Would also note participants included FEMA IV, TVA, and MVM representatives.

Why did it happen?
-LRD along with the seven district offices utilized the accepted and best practices procedures which have been in place for years. The Lead Districts for each state work closely with their state counterparts on training, exercises and yearly briefings on the Corps' authorities and missions assigned by FEMA during a declaration.

How can we do it better and who has the lead to fix?
-Sustain this activity.

Category: Emergency Management
10. Issue: Sustain response phase activities.

What was planned?
-An effective, coordinated, and timely response under Corps' authorities and missions assigned under the National Response Framework.

What actually happened?
-Pre-event posturing of appropriate resources was critical in our timely and effective deployment of ESF #3 personnel to FEMA IV Regional Response and Coordination Center and TN IMAT in support National Response Framework activities was on target. Our ESF #3 Team Leader arrived on time and date requested by FEMA IV as well as our TL on the TN IMAT arriving in Nashville ahead of FEMA personnel.
-Under Corps' Authority (PL 84-99) LRN EM responded to and fully supported TEMA requests for flood fighting. From issuing sandbags, providing technical assistance, to embedding a District EM in TN EOC, there were no unanswered requests for Corps' assistance. In one particular case, the LRN EM utilized reach back to a sister District (LRL) to virtually provide effective technical assistance and develop an appropriate course of action to sandbag a communication's facility potentially impacted by the rising waters.
-With one of two water treatment plants that supplies Nashville's drinking water impacted and off line, sandbagging assistance coordinated by LRN EM office with TEMA greatly mitigated impacts to the remaining facility as it remained online.
-Internal to Corps, with one of the LRN Projects (Cheatham) severely impacted and without communications, EM's timely and effective deployment of RRV #3 quickly established a communications platform for District personnel engaged in project recovery operations.
-Additional seamless coordination activities undertaken to mitigate impact to District resources was the utilization of National resources in support of Receiving Staging Onward Movement and Integration processing and FEMA Mission Assignments. With regards to RSOI, ULA assets at LRD were engaged to successfully accomplish for personnel arriving into the area of responsibility. RAO personnel identified and deployed to support preliminary damage assessment and project worksheet activities, here again, minimizing impacts to LRN's active workforce.

Why did it happen?
-Proven Business Practices that are validated during the annual Standard Operating Procedure Week, Corps/FEMA Remedial Action Program, the Senior Leadership Seminar and annual National Response Mission exercises.

How can we do it better and who has the lead to fix?
-Sustain this activity.

Category: Emergency Management
11. Issue: Sustain recovery phase.

What was planned?
- Execution of missions under the Stafford Act.

What actually happened?
-Six mission assignments were issued by FEMA Region IV to LRD. Division Office has the responsibility for executing the Regional Activation and the Nashville District is responsible for executing all other
-Working on orderly, physical and fiscal closeout of FEMA

Why did it happen?
-The Corps has well understood business practices that are exercised and validated annually with partner agencies.

How can we do it better and who has the responsibility?
-Sustain this activity.

Category: Emergency Management
12. Issue: Improve logistics response.

What was planned?

-During an event, seamless communication will be maintained between the Division Logistics Staff (Regional Logistics Liaison [RLL], Regional Logistics Planner [RLP], and Logistics Management Specialist) and the affected District Logistics Staff (Logistics Delivery Point [LDP]) to allow proper situational awareness and to facilitate rapid planning for the response effort, as well as, higher to ULA Logistics Activity Center (LAC) for guidance and potential reachback support.

What actually happened?

-Communication and information flow was extremely limited during the early phases of this event. Various members of the LRD logistics team were aware of different pieces of information before and during the weekend flooding event, which should have caused joint logistics preliminary coordinating meetings, an almost instinctive and intuitive sense for collaboration.

Why did it happen?

-The combination of the ULA Logistics Activity Center (LAC) displacement without communications due to floodwaters at the Naval Air Station, Millington, TN, and the rapidly evolving events in the Nashville area hindered the transfer of information and guidance to properly plan the support effort.
-The RLL, RLP, and LDP should have conducted teleconferences early in the event to ensure all logistics support requirements were well defined and activities were being conducted to satisfy those requirements.
-The RLL and RLP should have better communicated the requirements and status with the ULA Logistics Planning and Operations Division (LPOD) and leadership.

How can we do it better and who has the responsibility to fix it?

-The Regional Logistics Liaison (RLL) will develop a standard operating procedure (SOP) as to when to start preliminary coordinating meetings.
- For any event, RLL, RLP and Logistics Management Specialist (LMS) will establish and maintain clear and effective communications from the onset.
- LRD Logistics Management will develop a logistics work plan early in every operation that outlines all communication and reporting requirements. This work plan will anticipate a 24-hour presence, and therefore prepare for possible reach-back support if continuous operations are anticipated to last longer than 7 days.

Category: Emergency Management

13. **Issue: Improve continuity of operations for the ULA.**

What was planned?

-Clear lines of succession of the ULA leadership and key, critical tasks performed at the ULA Logistics Activity Center to allow continuity of operations if access to the LAC is denied.

What actually happened?

-The storm and flood's large geographical region included the ULA headquarters, located at the US Naval Air Station, Millington, TN. The base was flooded, knocking out all computer and telephone lines and nodes of communication on 2May. LRD Logistics RLL and RLP recognized this situation from afar in Cincinnati, OH and stepped up to fill the leadership void, providing both necessary national and local logistics guidance and priorities. The ULA HQ resumed communications and control on 7May.

-The effect of ULA leadership / guidance, reach-back support, and potential Logistics Planning and Response Team (LPRT) deployment during timeframe when LAC operation was impacted due to the flood in Millington, TN which prevented access to the LAC for 5 days.

-If a LPRT had been required during the early phase of this event, the ULA may not have been able to rapidly deploy a logistics team to assist the response effort.

Why did it happen?

-ULA Continuity of Operations Plan (COOP) was not finalized and key participants did not know their roles in the event of ULA COOP execution.

How can we do it better and who has the responsibility to fix it?

-ULA will finalize its Continuity of Operations Plan (COOP) to ensure critical tasks can be performed if its facilities are damaged or inoperable.

-The ULA will train and exercise the COOP plan after it has been developed.

Category: Emergency Management

14. Issue: Improve the Logistics support plan for no-notice events.

What was planned?

-LRN Logistics Delivery Point (LDP) will execute its 24-36 hour support plan when needed to support response to a no-notice event. Its plan will cover all facets of logistics support required to provide Reception, Staging, Onward movement, and Integration (RSOI) and initial life support to all responders processing into the flood zone.

What actually happened?

-Although LRN LDP staff effectively executed their support plan, this event showed the criticality of having an updated 24-36 hour plan to facilitate support during the early phases of a no-notice event. The plan should specifically outline what support will be provided to the EOC, district Crisis Management Team / Crisis Action Team, and incoming responders, as well as, who and how this support will be provided.

Why did it happen?

-The 24-36 hour support plan contained the guidelines to support any no-notice event, however, the magnitude of this event demonstrated additional detail and support planning is required within the plan.

How can we do it better and who has the responsibility to fix it?

-LRN LDP will update their plan and battle book based on lessons learned from this event.

Category: Emergency Management
15. Issue: Improve resourcing of the Logistics Planning and Response Team.

What was planned?
-All Logistics Planning and Response Team Members will deploy with the necessary equipment to conduct RSOI and logistics support operations.

What actually happened?
-LPRT members did not have (deploy with) required equipment. Both members of the LPRT deployed with personal cell phones.

Why did it happen?
-The individuals were not pre-issued government cell phones. The ULA does not have additional equipment to issue all members on deployment teams. To be fully effective, each member of the LPRT requires a laptop, with air card, portable printer, and a government issued cellular phone, preferably BlackBerry to sync with email. In this case, they could have secured phones from FEMA due to the FEMA logistics tail being fully set up, however, in other situations, each member must deploy with the equipment that will enable the team to operate and communicate during events where communications may be disrupted for extended periods of time prior to FEMA being available to provide such support.

How can we do it better and who has the responsibility to fix it?
-Logistics Point of Distribution will develop and procure "fly-away kits"; the kits must contain phones and portable computers that can be used to access the internet (ENGLink and Webmail) to assist with RSOI.

Category: Emergency Management
16. Issue: Improve logistics personnel ability to use ENGLink.

What was planned?
-The supporting logistics personnel (LDP and LPRT) will assist the EOC with receiving and in-processing all responders in ENGLink Interactive. All logistics personnel will be trained in the logistics attributes and functions within ENGLink.

What actually happened?
-The efforts of the deployed LPRT and district LDP personnel greatly assisted in the overall success of the mission. They in-processed 48 responders and ensured they had the proper paperwork and equipment. Once the LPRT members re-deployed to home station, the LDP staff resumed operations to ensure mission accomplishment.
-The only shortfall was proficiency in ENGLink processing. Not all logistics support members were familiar and proficient in the logistics and deployment module sections of the database.

Why did it happen?
-Key contingency logistics support personnel throughout the ULA are not familiar or proficient with ENGLink to effectively conduct RSOI operations. ENGLink training is neither a requirement for LDP staffs nor every member of LPRTs. Whether a LDP is executing its 24-36 hour support plan or an LPRT performing RSOI, there are several logistics functions, reports, and other tools in the system, which are vital to personnel / equipment accountability and overall success of any operation. For example: the logistics personnel supporting the operation must ensure the reporting instructions and RSOI details are provided to the EOC to ensure tasker templates are updated so responders know where to report, what lodging arrangements have been secured, etc.

How can we do it better and who has the responsibility to fix it?
-The ULA will add ENGLink Logistics / Deployment Module training to the Master Training Plan for all Regional Planners, LPRT members, Regional Logistics Liaisons, and LDP Chiefs.

Category: Emergency Management
17. **Issue: Develop duty descriptions for logistic team members.**

What was planned?
-Each logistics team member supporting an event should be assigned an appropriate duty description on a tasker in ENGLink.

What actually happened?
-Each logistics member supporting this event, not deployed as part of a LPRT, was tasked using the "Logistics Officer/Subject Matter Expert" duty description.

Why did it happen?
-Currently, there is no way to accurately select a LDP chief, LDP supply specialist, or transportation specialist for a tasker within ENGLink. The ENGLink system allows for requesting an individual with specific skill sets that are differentiated by the duty description, however, all applicable logistics duty descriptions have not been created.
-To effectively assign logistics team members to an event in ENGLink, duty descriptions must be available for every position within the LDP staff, RLP, and the RLL.

How can we do it better and who has the responsibility to fix it?
-ULA / LPOD will create duty descriptions for each applicable position (RLP, RLL, and LDP staff members) and work with ENGLink / RSC to update the Duty Description database.

Category: Water Management
18. Issue: Improve awareness of project maintenance status.

What was planned?

-Knowledge of the availability and use of turbines and spillway gates for use to manage project releases.

What actually happened?

-Old Hickory hydropower unit #4 was out of service during the event. This was an unscheduled outage. Unit #4 has been off-line for several months.
-Old Hickory spillway gate #1 was out of service during the event for scheduled maintenance. There was a bulkhead in place at the time of the flood that was overtopped when the lake level exceeded elevation 447.5. The other five gates were available and used extensively during this event.
-One of the four spillway gates at J. Percy Priest Dam did not operate initially when spillway gate releases were initiated late on May 3 (Monday). An Old Hickory Power Plant electrician was called in and within 30 minutes had diagnosed and repaired the problem. The repaired gate was then immediately put in service to prevent it from being overtopped.
-While all gates were mechanically available at Barkley Dam, they could not all be operated at the same time due to a submergence issue associated with exceptionally large project releases.
-While there were individual gate or turbine outages at other plants, none were of the nature to significantly impact project operations during the flood.

Why did it happen?

-Hydropower unit and spillway gate outages are common occurrences associated with operating and maintaining multi-purpose projects with individual components that have in some cases far exceeded their design life.
-The LRN Hydropower staff, both in the District Office and at the projects, routinely coordinates with Water Management on any outages that impact the ability of the project to release water. That was the case for Old Hickory where Water Management was aware that hydropower unit #4 was not available and that one of the spillway gates had been taken out of service for maintenance. The issue with the spillway gate at J. Percy Priest did not become apparent until it was being operated during the event.
-With Old Hickory spillway gate #1 not available during this event it forced the five available gates to be operated at larger gate openings. The maximum gate opening during this event was 34 feet. The maximum gate opening for Old Hickory spillway gates is 42 feet. Therefore, with one gate not readily available the project was still able to pass the required flow.

How can we do it better and who has the lead to fix it?

-LRN will develop and disseminate a tracking system that identifies in real-time what project components (turbines, spillway gates, sluice gates, fixed cone valves, etc.) are available for use.
-Water Management and LRN Operation elements responsible for scheduling maintenance outages will enhance communication to ensure that scheduled maintenance can be performed at the best time with respect to water control operations.

Category: Water Management
19. Issue: Improve triggers for activation of Water Management offices.

What was planned?
-Maintain Water Management operations during a flood event.

What actually happened?
-LRD was in communication with the OHRFC since Wednesday.
-On Friday, April 30, LRD WM directed the District offices to work the weekend. LRD staffed its office for Saturday and Sunday during morning business hours.
-On Saturday, LRD initiated communication with TVA/LRN/NWS anticipating the need to initiate Lower Ohio/Mississippi River flood control operations. LRD did not arrange for 24-hour staffing because TVA River Scheduling staffs 24/7 routinely and has standing orders to contact LRD personnel at home during rapidly changing conditions. LRD does not have enough water management staff to man the office on a 24-hour basis. LRD WM does not have a Standard Operating Procedure for 24-hour operation.
-LRN typically staffs the Water Management office with one water manager on weekends and holidays. During routine operations all evaluations and coordination are complete and the necessary instructions issued to the projects by noon. LRN WM does not have a Standard Operating Procedure for 24-hour operation.
-LRN WM followed established procedures by staffing the office with a highly experienced water manager on Saturday morning. The water manager, through coordination with other personnel and the Water Management Section Chief, implemented a number of measures to respond to changing conditions. Prior to leaving at 1340 hours, the water manager issued a number of instructions to operators at the projects on how to respond to changing water conditions.
-There was a 15.5 foot rise in the Nashville gage on Saturday, most of which occurred during the afternoon.
-Kentucky and Barkley pools rose 4 feet from Saturday night to Sunday morning.
-LRN WM (senior water manager that worked earlier in the day and the Section Chief) returned to the office at 1900 hours to complete a supplemental evaluation of rainfall, runoff, and project conditions and to make any needed adjustments. Prior to leaving the office at 2300 hours a new set of instructions (including when to call during the night for additional guidance) were issued to the projects and an e-mail was sent out to LRN management and LRD WM. LRD WM forwarded the LRN WM email to the NWS OHRFC at 0416 hours Sunday morning. NWS OHRFC read the email at 0700 hours.
-NWS OHRFC attempted to contact LRN WM Saturday evening and Sunday morning prior to anyone coming to office.
-Conference calls between LRN and the NWS OHRFC began at 0830 hours on Sunday.
-The LRN WM Section Chief contacted staff on Saturday evening and made arrangements for 24-hour operations to start with the 0630 hours shift on Sunday morning. The office was staffed around the clock until 2200 hours Tuesday night.
-The NWS WFO maintains 24/7/365 operations.
-The NWS Nashville WFO has a Nashville Hydrologic Program Manual which contains at least one off-hour contact number for LRN.

Why did it happen?

-An experienced LRN water manager was on duty Saturday until 1340 hours and returned at 1900 hours and remained in the office until 2300 hours. The situation at the time did not appear to warrant around the clock staffing as late as Saturday afternoon.

-The NWS OHRFC standard operating procedure is to include the Corps' release schedule into its forecast. Beginning very late Saturday night and into early Sunday, May 2, the NWS OHRFC needed to know how LRN was operating the projects and could not contact anyone in Nashville. Calls to LRN were placed at approximately 2200 hours Saturday, and 0600 hours and 0700 hours Sunday. No voice messages were left on LRN WM telephones.

-Although they had off-duty contact information, NWS OHRFC did not attempt to contact LRD WM until Sunday morning to obtain contact information for LRN WM.

-The NWS OHRFC did not try to contact LRD WM until 0615 hours Sunday morning. The NWS OHRFC was advised to call LRN at 0730 hours by LRD.

-The TVA River Scheduling night shift did not contact LRD WM. Inexperienced personnel were on duty and they did not know who to contact.

-LRD and LRN WM should have begun 24-hour operations Saturday to provide continuous monitoring and communications with NWS and TVA.

How can we do it better and who has the lead to fix it?

-LRD WM will consider NWS Chat via BlackBerry.

-Water Management is developing a common trigger for 24-hour operations and increased communication. Trigger may be based on rate of rise, predicted crest, QPF, etc. and may be based on the basin. This will be accomplished by developing a Standard Operating Procedure (SOP) that will define when to initiate 24-hour flood operations, staff levels and schedules, and frequency of increased communication. The SOP will include how to assist Water Management due to lack of personnel (illness, etc.), loss of equipment or loss of office. The SOP will include additional support to Water Management such as administration support to answer telephones, faxes, etc. and liaisons to other offices, etc. This SOP will allow Water Management to stay focused on its mission.

-TVA and NWS OHRFC will utilize the contact information to contact personnel during off-duty hours when the situation is rapidly changing and the established triggers have not been reached.

-The Corps will share off-hours contact information and insure it is maintained with up to date information.

-TEMA can provide contact numbers for key staff at the various agencies and is willing to provide assistance.

-LRN WM will share system operation plans with TVA River Operations staff. This would provide a continuous 24/7 source of information on the Cumberland River system projects.

-LRN is expanding current cross-training of LRN Water Resources and LRN WM personnel.

-LRD WM will evaluate the necessity to increase staff versus leveraging existing capabilities in other Water Management offices. Note that LRD WM has been approved to increase staff by 2 employees beginning in FY2012.

-Insure LRD and LRN water managers are monitoring situation in afternoon and evening hours as well.

Category: Water Management

20. Issue: Improve the understanding of technical information between the Corps and the National Weather Service.

What was planned?

-Provide effective communication of project operations with the NWS.

What actually happened?

-Misunderstanding of technical information and the frequency of communication regarding the operation of Old Hickory Dam.

-Frequency of information exchange under existing communication protocols between the NWS and Corps was inadequate for this type of rapidly changing event; additional conference calls beyond the morning and afternoon calls were not requested by the NWS; the Corps did not understand that the NWS wanted spillway gate changes as they were made.

-Due to the chaotic nature of the flood event and the frequency of required spillway gate changes, LRN water managers did not provide estimated Old Hickory discharges to the NWS as gate changes were made on Sunday, May 2. On Sunday afternoon the Corps was dealing with multiple issues along the mainstem of the Cumberland from Cordell Hull to Barkley including record discharges at several projects. Old Hickory was above the surcharge pool and near the pool of record.

-During 1330 conference call on Sunday, LRN WM indicated that the surcharge pool was fully utilized and assumed the NWS understood the Corps was passing all inflows and would change their modeling approach accordingly. However, the NWS assumed that since the Corps was operating the spillway gates (ie., the gates were not all fully raised in the free-flow position), the gate-rated discharges at the time of the conference calls were still reflective of current flow conditions later in the afternoon and into the evening. The NWS continued to use the information provided during the conference calls as the primary basis for NWS forecasts on the mainstem Cumberland River.

-NWS should have considered that with the surcharge pool fully utilized, all inflows at Old Hickory Dam would be passed downstream to prevent additional rises in the Old Hickory pool.

-When the NWS OHRFC reservoir model indicated higher outflow, they deferred to the release information provided directly by the Corps, unless they had other data to tell them otherwise (such as real time tailwater readings to confirm and/or adjust the model). Due to the lag time for flow between Old Hickory and Nashville, it was late evening before they recognized that the flow information provided during the scheduled conference calls by the Corps was no longer valid.

-An evening conference call was not requested by the NWS OHRFC at the time of the afternoon call on Sunday, May 2. Neither the Corps nor the NWS could foresee the excessive rainfall that continued to drive rapidly changing conditions into the evening. Information was exchanged late in the evening first from LRN WM through the Nashville WFO to the NWS OHRFC then via direct conversations between the NWS OHRFC and LRN WM.

Why did it happen?

-A misunderstanding of technical information and frequency of communication between agencies, i.e. LRN intended for its conversations to indicate that they were operating the gates to pass the inflow while maintaining the Old Hickory pool and that the discharges were above their gate rating curves. The NWS felt that since the Corps was operating the gates, the project was not passing inflows and the afternoon discharges were reflective of the evening conditions.
-Corps and NWS assumed each was aware of what the other agency meant by their operations and modeling. For example, the Corps indicated on teleconferences that Old Hickory's flood surcharge pool had been utilized and assumed the NWS was aware that project was passing inflow with gate operations.
-Discrepancies between NWS hydrological simulations and Corps' release projects (outflows) were never successfully resolved on Sunday as rainfall exceeded the forecast and the river stage approached critical levels in Nashville. These misunderstandings affected the accuracy of the NWS OHRFC forecasts to some degree.
-The Corps provides the NWS with observed project data, precipitation data, stage, and flow data from Corps' stream gages, and forecasts of project releases and lake levels from the Corps' multipurpose projects. The forecast data provided by the Corps is for the current day and the next five days and is for eight of the ten projects within the Cumberland Basin. LRN WM does not prepare a daily forecast of lake level and project releases for either Martins Fork Dam or Laurel River Dam. Information is provided for the other eight projects within the Cumberland Basin reservoir system. Corps of Engineers forecast information is based on rain on the ground as of 0600 (Central Time) on the forecast date. Given the dynamic nature of river flows and stages at the mainstem Cumberland River projects during a significant rainfall event, the LRN WM discharge forecasts for the mainstem navigation projects (Cordell Hull, Old Hickory, and Cheatham) cannot be relied upon to develop stage crest forecasts for the damage centers. During extreme events like the one observed in May 2010, LRN water management operations at navigation projects (Cordell Hull, Old Hickory, and Cheatham) are driven by runoff from their uncontrolled drainage areas, and can be characterized as reacting to match increasing inflow levels. Conversely, at the Cumberland Basin flood storage projects (Wolf Creek, Dale Hollow, Center Hill, J. Percy Priest, and Barkley) where large flood control pools are available to capture local runoff, meaningful long-range (3 – 5 day) forecasts can be developed. Due to these constraints, the standard data exchange practice between LRN WM and NWS OHRFC during high flow events (for 30+ years) has been to continue with the daily data exchange and to supplement that with discussions on the water control plans for the flood control projects – specifically Wolf Creek, Dale Hollow, Center Hill, and J. Percy Priest. LRN WM's understanding of the modeling approach employed by the NWS OHRFC was to pass inflow at the navigation projects where only the surcharge pool storage was available and to route the releases from the flood control projects to develop stage forecasts at the damage centers. This assumption was based on 26 years of experience by the current LRN WM senior forecasters during which, this procedure had been followed for 16 high flow events when the Nashville stage had exceeded 30 feet. The NWS OHRFC was basing crest forecasts on modeling that applied mainstem release patterns discussed during the coordination calls. In reality, the conditions at Cordell Hull, Old Hickory, and Cheatham were so dynamic that discharge information relayed during the calls quickly became outdated. LRN had discussed conditions at the navigation projects to portray the serious nature of the flooding observed at those projects, and not with the understanding that the NWS OHRFC was applying the discharge information in their hydraulic models. As a result, LRN WM did not recognize the need to update that information as it rapidly

changed throughout the afternoon and evening on Sunday, May 2. Once that expectation was realized, LRN WM readily shared updated spillway release information with NWS OHRFC.
-Increased communication was delayed until late Sunday night when an OHRFC forecaster called LRN shortly after arriving on shift (approximately 2300 hours Sunday, May 2.)
-There was not an established procedure to update the project operational data after the initial morning and afternoon data exchange with the NWS.

How can we do it better and who has the lead to fix it?

-The Corps and NWS will develop a better understanding and appreciation of each other's models, operations and how to alert each other of changing conditions.
-LRN will conduct annual Flood Table Top Exercises with NWS, USGS, TEMA and others as appropriate to improve understanding of reservoir system operations and strengthen communication ties among the agencies.
-LRN WM will review and revise the water control manuals to insure they address extreme events and update as necessary. Extend gate ratings and update other critical guidance for above and below normal ranges.
-LRN will develop electronic updates for the tailwater conditions at the Corps' dams.
-LRN will investigate options to provide real time communication with the NWS regarding water releases from Corps' projects. Example: Remote monitoring of gate operations similar to gates at Smithland Lock and Dam on the Ohio River. In the short-term implement procedures for the operators at the projects to notify the NWS WFO when they make spillway gate changes during flood operations.
-LRD WM will evaluate NWS Chat to assist with communication.
-LRN WM will develop a Standard Operating Procedure (SOP) that will define the protocol and frequency of increased communication. Critical operations personnel must be able to be reached at all times (off hour phone numbers, cell phones, etc.). When critical changes are made by either the Corps or NWS, phone calls must be initiated. The SOP will include common triggers for increased communication that are coordinated with the NWS. Trigger may be based on rate of rise, predicted crest, QPF, etc. or may be based on the basin.
-LRD WM will continue working with the NWS to develop joint models.

Category: Water Management

21. Issue: Implement redundant Water Management Enterprise Architectural (WMEA).

What was planned?

-Maintain Water Management operations (enterprise and legacy systems) during a flood event, including uninterrupted access to water control data during the flood event.

What actually happened?

-Network outage at LRN started at 0930 hours Sunday morning and persisted until 2005 hours that night as a result of a Verizon communication line break.
-This impeded LRN WM staff's ability to obtain data and post project data.
-LRN water managers found alternative ways to obtain gage data, such as using personal cell phones with internet access.
-A call was placed to the Corps' Information Technology Office (ACE-IT) Service Desk at 1124 hours Sunday morning. ACE-IT did not issue a ticket; however, they did respond later that day at 1930 hours with a wireless router equipped with an air card that allowed access to the internet by Water Management staff that had laptops (limited to two staff members).
-The LRN WM database is located outside of the production network which prevented access to the data when the internet failed.
-During the network outage updated information was not placed on the Corps' website; therefore, it was not readily available to other agencies or the general public.
-The local readout ground station (LRGS) equipment located at the J. Percy Priest Water Management COOP site had been in-place for only a week following a lengthy outage to allow ACE-IT migration of software to an updated platform. The LRGS had experienced network issues due to local (J. Percy Priest project) connectivity and power problems at the site. There was uncertainty concerning the functionality of the LRN LRGS system. However, based on subsequent evaluations the COOP site was functional and available during the event.
-NWS not aware that LRN gage data was also available on Rivergages.com
-LRN fielded numerous calls from the public requesting gage information.
-The flow of rainfall, stage, and flow data was disrupted by a prolonged network outage that occurred on May 2 (Sunday). During this time any data streams that were dependent on a functioning network were not available.
-Prior to this event LRN was in the process of relocating the water control database from outside of the production area to inside the production area. The location of the database did not interrupt the access to data during the event.

Why did it happen?

-Major network communication line (by external provider) went out during event.
-ACE-IT did not provide Priority 2 Critical Service upon request as listed in Performance Work Statement (PWS) Technical Exhibit 9 and in accordance to the ACE-IT/Water Management Memorandum of Agreement, dated August 25, 2008.
-Local ACE-IT mandated the water management database be outside the production network rather than on the water management subnet as in other offices.

-Under certain circumstances, ACE-IT should not be allowed to set the priorities for requested work or services related to critical water management operations.

How can we do it better and who has the lead to fix it?

-LRN has purchased air cards, laptops and cell phones for the Water Management staff to provide redundant internet capability and evaluating alternatives for internet access.
-LRN WM will establish water management subnet with a controlled internet accessible segment and move the water management database back inside the production network.
-LRN has a local COOP site located at the J. Percy Priest Lake project. Given the close proximity of the COOP site to the Water Management Office, power, network, and/or weather related issues would likely affect both sites simultaneously. Accessibility also becomes an issue during an event like the May 2010 flood when access to the local COOP site was difficult at best during extended periods of time. Trigger points should be established that would lead to pre-positioning staff at the local COOP prior to access becoming limited.
-LRN will evaluate establishing a long distance COOP Site where a redundant database and modeling capability are maintained in a ready state. The logical arrangement would be for LRL and LRN to set up reciprocal COOP Sites.
-ACE-IT (Service Assurance Officer, CECI) will provide the service listed in the Performance Work Statement Technical Exhibit 9 and the ACE-IT/Water Management Memorandum of Agreement, dated August 25, 2008. The ability to affect priorities on ACE-IT actions in preparation for and during an event needs to be enhanced.
- Corps' Water Management System (CWMS) could not have been run during the time of the network outage. An alternate connection to CWMS at the COOP site or long distance coop will be established.
-LRN WM will evaluate a local readout ground station (LRGS) at the District office for satellite telemetered data to be received independent of the internet.
-The USGS, NWS, and Corps will provide www links between their web pages such that the public is aware that data is also available on other agency web sites.
-Corps and USGS web sites will contain notes to reflect that the NWS is responsible for river forecasts and provide a link to their web site. Note that the NWS OHRFC provides guidance to the WFOs who are responsible for issuing forecasts and warnings.
-LRN WM will complete the relocation of the water control database to within the production area. This will require a subsequent update to the method used to transmit data to the Southeastern Power Administration (SEPA).
-LRN WM will develop alternative methods to interface with water control data that are not solely dependent on the network.

Category: Water Management

22. Issue: Improve communication between the Corps and the National Weather Service.

What was planned?

-Provide effective communication regarding project operations with the NWS.

What actually happened?

-When the NWS OHRFC was contacted to inform them of high releases from Kentucky Lake and Lake Barkley, the staff on duty asked LRD WM to contact the Paducah WFO directly. The NWS OHRFC did not advise LRD WM to contact the LMRFC but advised to contact the Paducah WFO. LMRFC is responsible for forecast operations downstream of Barkley, while WFO Paducah is responsible for issuing all watch/warning products for this area.
-NWS Paducah WFO issued a Special Weather Statement to address the high releases from Kentucky Lake and Lake Barkley; a Flash Flood Warning would have activated the Emergency Alert System.

Why did it happen?

-The staff at the Paducah WFO did not fully understand the information. The flow information that was provided was not translated to stage, thus the extent of the increase was not recognized.
-Technical communication and understanding of each agency's operations played a large role in this misunderstanding.
-NWS can only convert flows to stages at NWS rated forecast points. There are no forecast points on the Cumberland River downstream of Barkley.

How can we do it better and who has the lead to fix it?

-The Water Management office will translate flows to river height levels, as necessary, when working with the WFOs.
-LRD WM LMRFC and the OHRFC will develop an interagency process that specifies the correct language and emergency activation system levels for communicating urgent events regarding operation of Corps' projects. This will ensure a common operational picture and appreciation for rapidly developing events.

Category: Water Management
23. Issue: Sustain pre-event water management actions.

What was planned?
-Adjust lake levels prior to rainfall event.

What actually happened?
-LRN WM makes nearly all operational decisions based on rain on the ground. The exception is a relatively short suspense (3 days or less) rainfall forecast that carries a high degree of certainty. Given that scenario it may be appropriate to make adjustments to Cumberland River Basin lake levels in advance of the event to better position the system to respond to significant increases to project inflow. That was done for this event on Thursday and Friday prior to the heavy rain that began on Saturday when pool levels at Cordell and Old Hickory were lowered about 0.5 ft and Cheatham was lowered by around 1.0 ft.
-The challenge in pre-positioning lake levels is that by the time there is enough confidence in a rainfall forecast to warrant taking proactive measures there is not enough time to significantly lower lake levels and clear the water from the system to avoid merely moving the problem downstream. That was the case during this event given the situation on the Ohio River where the river was nearly at flood stage at Cairo when the Cumberland event began and a flood crest was moving down the Ohio.
-The decision to lower lake levels at the main-stem projects was based on modeling of forecasted rainfall performed by LRN WM. LRN currently has two system water control models available. The RAI Model (vintage 1978) is the production model and has been in use for more than 30 years. LRN, in conjunction with work being done by a contractor, is in the process of developing a Corps' Water Management System (CWMS) application for the Cumberland Basin reservoir system. The CWMS model is a system of real-time data analysis tools and hydrologic models that will also utilize radar precipitation data provided by the NWS. The CWMS model is in draft form. It was used leading up to this event to perform simulations of forecasted rain. These model runs looked at project response at Wolf Creek and Center Hill (DSAC I dams) in addition to conditions on the Cumberland River. The simulated runs were coordinated with similar efforts performed by water managers at LRD and TVA to develop a regional view of the forecasted event.
-LRD WM issued instructions to the districts to work Saturday/Sunday. Note that LRN works all holidays and weekends.

Why did it happen?
- Although precipitation forecasts have improved, it will still take significant advances in the science behind rainfall and runoff forecasts to reach a point where lake level adjustments of a magnitude necessary to effect significant flood crest reductions can be made in advance of a major rainfall event. A shift of only 50-100 miles of the rainfall from the May 2010 event would have completely changed the outcome.

How can we do it better and who has the lead to fix it?
-LRN WM will continue CWMS development for the Cumberland Basin and replace the older RAI model for daily production use.

-Water Management and the NWS will develop a program that takes advantage of tools currently either in use or under development at NWS to prepare project inflow forecasts based on the latest forecasted rainfall information. The hydrology modeling could be performed by NWS and provided to the Corps to evaluate using CWMS. The early stages of such a process are currently in place with NWS providing a daily update of inflows to Wolf Creek and Center Hill. The NWS is experimenting with several different methods of utilizing probabilistic QPF. It is currently providing to some of its partners the experimental MMEFS (Meteorological Model Ensemble Forecast System) and the experimental probabilistic QPFs prepared by the Hydrometeorological Predication Center, along with several other experimental QPF ensembles.
-The Corps and the NWS will continue to evaluate a common modeling approach to facilitate a consolidated approach to hydrology and hydraulic modeling.

Category: Water Management
24. Issue: Improve awareness of the Quantitative Precipitation Forecasts.

What was planned?
-Awareness of QPFs issued by the NWS during the flood event.

What actually happened?
-QPFs and experimental probabilistic QPFs are published twice daily in the early morning and late afternoon/evening by the Hydrometeorological Prediction Center (HPC). As a result they often first become available when the LRN WM office is not staffed. As a result, revision to a QPF that may warrant action (revise project releases, increase staffing, etc.) by LRN water managers may not be seen until many hours after it was issued. During the May 2010 event the QPF published on Friday evening was not observed until Saturday morning at 0700 hours when LRN WM staff reported for duty. A review of this QPF was warranted; however, it did not impact flood operations.

Why did it happen?
-NWS publishes the QPFs on a twelve hour time basis.
-LRN water managers do not routinely check the evening QPF after duty hours.

How can we do it better and who has the lead to fix it?
-Look at another alert measure to alert key personnel.
-LRD, the Districts, OHRFC and the WFOs will update their contact lists so that the OHRFC can alert the appropriate office if significant changes occur in the evening QPF.
-LRD WM will consider NWS Chat via Blackberry.
-LRN WM will assign a water manager the responsibility to check evening QPFs.
-Note that the OHRFC will expand ensemble probabilistic forecasting (MMEFS – meteorological model ensemble forecast system) to all Corps' districts in the near future. MMEFS Training will be provided this summer. In addition, the OHRFC has begun to provide MMEFS inflows for Wolf Creek and Center Hill to address risk to high risk dams.

Category: Water Management

25. Issue: Improve situational awareness of the National Weather Service published forecasts.

What was planned?

-Awareness of crest forecast by the NWS during the flood event.
-Assist NWS by insuring that project operations do not differ from those that were used to develop the crest forecast.

What actually happened?

-NWS developed revised flood crest forecasts and LRN WM was not immediately aware of the new forecast. This occurred on Sunday evening. LRN WM was coordinating releases from Old Hickory and J. Percy Priest based on an early Monday morning crest, and was not aware that the crest had been pushed back to early Monday afternoon.

Why did it happen?

-NWS not aware that LRN WM was not receiving forecasts directly.
-LRN WM was not aware of alternatives to receive the NWS forecasts.

How can we do it better and who has the lead to fix it?

-LRN WM will investigate possibility of receiving NWS forecast provided through email notification.
-LRN WM staff has acquired Blackberries.
-LRN WM will configure Local Data Management (LDM) systems to receive the NWS suite of products in real-time from LRD. LDM system may also be configured to provide email notification of forecasts.

Category: Water Management
26. Issue: Improve long term reliability of rainfall and stream gages.

What was planned?
-Continuous operation of rainfall and stream gages to provide the information necessary to support flood fight efforts.
-Repair gages as necessary during the event to support the continuous flow of data.

What actually happened?
-Operation and maintenance of rainfall and stream gages within the Cumberland Basin is executed by a combination of LRN WM staff, contract personnel, and the USGS.
-The LRN stream gaging maintenance contract expired on April 30, 2010, the day before the high rainfall for this event started. Emergency repairs were performed by LRN WM staff. Only four LRN gages were damaged by the flood. They consisted of two stream gages (Harpeth River at Kingston Springs and Bledsoe Creek at Gallatin) and two tailwater water quality monitors (Old Hickory and Cheatham). The Harpeth River site was the most critical as it is a NWS forecast point. The gage was repaired and brought back online within one week of when the high water flooded out the electronics. The Bledsoe Creek gage was reinstalled at a later date.
-The Tennessee USGS office contacted LRN WM on Wednesday (May 5) and offered to set up temporary gages at locations where gages were damaged or destroyed. They also offered to make stream flow measurements at key locations. There was not a need for any temporary gages, but the USGS did make several flow measurements that will provide valuable information for documenting the flood.

Why did it happen?
-The Harpeth River experienced what appears to be a greater than 500-year event that overtopped the gage equipment by several feet.
-There is not a viable location for the Bledsoe Creek gage that does not place it in harm's way for extreme events.
-The Old Hickory tailwater water quality monitor is located on the lower lock wall and is vulnerable to greater than 100-year events.
-The Cheatham tailwater water quality monitor was located on the left descending bank and was also susceptible to damage from high flows.

How can we do it better and who has the lead to fix it?
-LRN WM recently completed a thorough evaluation of its gaging program with respect to establishment of the Cumberland River Basin CWMS application. This indicates that individual gage locations need to be evaluated with respect to inundation potential.
-LRN is entering into a formal partnership with the Kentucky and Tennessee USGS offices through participation in the Cooperative Stream Gaging Program. LRN has a gage transition plan that supports this action.

Category: Water Management
27. Issue: Sustain the ability to operate projects under extreme conditions.

What was planned?
-Operate the Cumberland Basin reservoir system using the water control manuals.

What actually happened?
-The magnitude, duration, and location of the rainfall were such that flood stages along the Cumberland River were pushed to new record levels during the event.
-Information contained in the water control manuals did not cover the full range of operations required to respond to this record rainfall event.
-LRN water managers were working with incomplete data sets, access to the District Office was difficult, and multiple demands were placed on staff to provide information and brief officials, both in-house and external. Reservoir system operations were further hampered by a prolonged network outage that occurred on Sunday. The three LRN WM team members making the operational decisions each had thirty plus years of direct water management experience and had been through multiple high water events in the Cumberland River Basin. Their experience of knowing when and how to deviate from direct application of the water control manuals can be credited with preventing additional damages and perhaps saving several lives in the basin.
-A chronological analysis of water control actions taken during this event is presented below. Where appropriate, an explanation of deviation from operations detailed in the water control manuals is included.
-In order to evaluate the impacts of water control operations that were outside of the guidance presented in the water control manuals, a detailed analysis using sophisticated hydrology and hydraulic modeling was required. This analysis required taking existing model components and combining them into a system model. In turn, this model was calibrated to the May 2010 flood event. Given limitations with respect to time and resources, a preliminary analysis of actual and water control manual guidelines were completed using a detailed Hydrologic Engineering Centers River System Analysis (HEC-RAS) model. In this analysis, the modeler was able to employ an iterative approach to project operations to meet water control guidelines and reduce downstream impacts. However, during the actual event, Corps' water managers were not afforded this opportunity. They were placed in the position of making multiple time-sensitive decisions spaced across multiple projects within the Cumberland Basin and to do so without the availability of a detailed model. The results of the HEC-RAS model evaluation are included where appropriate in the following sections of this report.

29-30 April 2010: Thursday and Friday
-Based on the NWS rainfall forecast (Quantitative Precipitation Forecast (QPF) products) indicating significant rainfall (3-5 inches within the Cumberland River Basin) starting on Saturday, May 1, LRN WM made the decision to pull some water out of the mainstem projects in advance of the storm. The lake levels at Cordell Hull and Old Hickory were lowered approximately 0.5 feet. The Cheatham pool was lowered about 1.0 foot. This was not completed until Saturday, May 1 prior to the initial heavy rainfall. These actions were taken to better position the reservoir system to be able to respond to the forecasted rainfall totals.

- This is a typical operation to manipulate lake levels within normal operating ranges. It is better characterized as an adjustment as opposed to a significant change.

1 May 2010: Saturday

-1000 hours - The hydropower unit at J. Percy Priest and one of three units at Center Hill were each brought on-line at 1000 hours and run continuously for the remainder of the day. These decisions were based on observation of the radar rainfall amounts and the near certainty that both the Stones River and Caney Fork Watersheds were going to receive excessive rainfall.

- These are typical same day adjustments to the hydropower generation schedule needed to react to changing hydrologic conditions. The J. Percy Priest hydropower unit was not scheduled to be run on this date. It was brought online at 1000 hours. Center Hill had eight hours of generation scheduled for May 1. Once one unit was brought online at 1000 hours it was left on for the remainder of the day. The action at Center Hill was taken to conserve flood control storage and manage the lake level in accordance with the Interim Risk Reduction Measure (IRRM) pool restriction for a Dam Safety Action Classification (DSAC) I dam. The additional flow did not pose a threat to Carthage, TN, the immediate downstream damage center.
- Wolf Creek was operating four hydropower units around the clock in response to rain, which fell about one week prior to this event. The pool elevation at this time was 682.92. Wolf Creek operates with a DSAC I IRRM pool restriction target elevation of 680 ft. The lake level at Dale Hollow was elevation 650.16. One hydropower unit was running around the clock for lake level management.
- Section 2.4.5 of the Old Hickory Water Control Manual states "The size of the surcharge storage pool was derived considering flows expected while the storage reservoirs were being emptied. It was not intended to also compensate for heavy local runoff simultaneous with peak releases from Wolf Creek, Dale Hollow, and Center Hill."

1200 hours – Spillway discharges are initiated at Old Hickory.

- The spillway discharge was increased at a rate of approximately 5,000 cfs/hr in accordance with the water control manual until a total flow of 75,000 cfs was reached.
- LRN WM made the decision to not apply the Nashville crop season control limit of 54,000 cfs. According to the water control manuals, crop season is generally understood to be from April 15 through December 15; however, these dates may be adjusted depending on actual field conditions. Flood season is designated as anytime other than crop season. Since the area had experienced an average of two inches of rainfall approximately a week before, and with the limited agricultural activity observed in this reach of the river, the flood control flow of 90,000 cfs was selected for use. Therefore, by going to 75,000 cfs out of Old Hickory, an additional capacity of 15,000 cfs was reserved for a combination of J. Percy Priest releases and local runoff from the 275 mi^2 of local uncontrolled runoff between Old Hickory Dam and Nashville. The objective of this course of action was to keep the Cumberland River from reaching flood stage at Nashville.

1730 hours – Spillway releases are initiated at Cordell Hull.

- The spillway discharge was increased at a rate of approximately 5,000 cfs/hr in accordance with the water control manual until a total flow of 50,000 cfs was reached. When the pool reached elevation 505.25, the flow was increased to 60,000 cfs. The

control flow of 72,000 cfs for flood season was used for Carthage. Therefore, by going to 60,000 cfs out of Cordell Hull, an additional capacity of 12,000 cfs was reserved for a combination of Center Hill releases and local runoff from the 420 mi^2 of local uncontrolled runoff between Cordell Hull Dam and Carthage. This action was taken in an effort to keep the Cumberland River from reaching flood stage at Carthage.

- When the Cordell Hull discharge reached 60,000 cfs at 2400 hours on Saturday, May 1, the discharge was held steady in an effort to limit the volume of water entering Old Hickory Lake.
- A total of three spillway gate changes were made on May 1.

1900 hours – Cheatham goes to free flow.

- The Cheatham Lock and Dam was designed to allow overtopping of the lock and spillway gate section without threat of failure of the dam. The power plant is at a higher elevation and does not become inundated during extremely high flows such as those observed during this event. When the river flow past Cheatham exceeds the flow that can be regulated by the seven available spillway gates, the gates are lifted out of the water and the river goes to what is referred to as free flow. In this condition there can be very little difference (less than 1 ft) between headwater and tailwater elevations.

2300 hours – 75,000 cfs outflow reached at Old Hickory

- This outflow was maintained to allow time for excessive local flows to recede downstream.
- A total of nine spillway gate increases were used to reach 75,000 cfs on May 1**.**

2 May 2010: Sunday

0930 hours – The district office lost network access and no real time data was available until it was restored at 2005 hours. The phones were still working and project data was available when projects were called.

1000 hours –Releases from Old Hickory had been managed overnight to hold Nashville to the control flow limit and keep the river below flood stage. As a result the headwater elevation at Old Hickory had risen to elevation 447.75 at 0600 hours. Intense storms that started around 0700 hours on May 2 had already dumped in excess of three inches of rainfall onto saturated ground in the Nashville and Old Hickory area by 1000 hours. A series of spillway gate increases were made at Old Hickory as LRN water managers reacted to rapidly increasing lake levels resulting from runoff from the local uncontrolled basin to Old Hickory Lake.

- The Old Hickory Water Control Manual limits spillway gate increases to 5,000 cfs/hr. This rate of increase is not to be exceeded until the headwater elevation reaches the top of the surcharge pool. At that point the water control manual states that the discharge is increased as necessary to maintain the water surface at the top of the flood surcharge pool, elevation 450.0. It quickly became apparent that the Old Hickory Lake level could not be adequately managed by adhering to this requirement. Project releases were managed in as controlled a method as possible. However, spillway discharge increases as frequently as every 15 minutes and some by as much as 10,000 cfs were necessary to prevent the upstream lock wall from being overtopped. By following this course of action, a one step increase in discharge of a magnitude to match project inflows was avoided. This allowed LRN water managers to reduce the rate of rise in the Old Hickory pool by continuing to maintain controlled releases from the project. Ultimately, by

maintaining control at Old Hickory Dam, a reduction of downstream flood impacts was realized.

- Figure 1 presents stage hydrographs and flow at the Nashville gage for two modeled scenarios. The red lines are a model representation of the actual operations. The blue curves represent the scenario where strict adherence to the water control manuals was maintained. A significant divergence can be observed in the two sets of curves beginning late Saturday night, May 1, and extending through Monday (May 3). If LRN water managers had made the extreme spillway gate increases necessary to prevent the Old Hickory Lake level from exceeding the top of the surcharge storage pool, elevation 450.0, that action would have resulted in Nashville area flooding that would have started several hours earlier and would have been characterized by a more aggressive rate of rise than what was observed during the event. The difference in ultimate flood crest between the two scenarios was not significantly different.

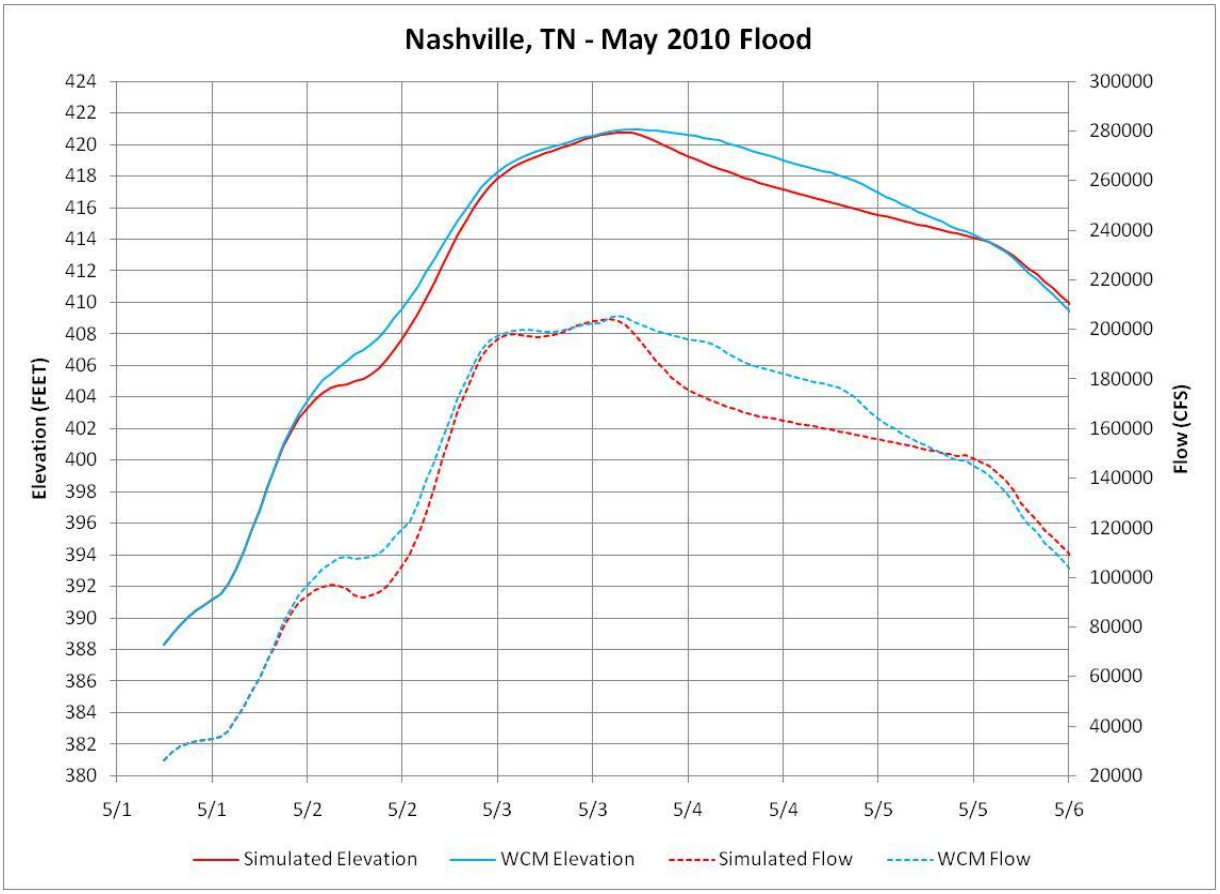

Figure 1 - Comparison of Stage Hydrographs and Flow Rates for Simulated.

- Operations and water control manual operations at Nashville. The water control manual states that "When the headwater rises to elevation 450, the 5,000 cfs per hour limitation will no longer apply and releases may be increased as necessary to prevent any further rises in the headwater." Despite the numerous spillway gate increases employed, the Old

Hickory lake level exceeded the top of the surcharge pool, elevation 450, and by 1400 hours had reached a new pool of record of elevation 451.45. At this point, water was only 6.6 inches from flowing over the upstream lock wall, and threatening continued operation of the project. If the powerhouse had been flooded, plant staff would have been required to pull the gates out of the water and abandon the project. An analysis of this scenario indicates that if that had occurred the stage would have been approximately four feet higher at the Nashville gage.

- During the event, one of the six spillway gates was out of service for scheduled maintenance. The maintenance being done on the gate required the bulkhead to be put in place and a great deal of equipment and scaffolding to be in the immediate area which prevented it from being put back in service. Ultimately, following a total of 19 spillway gate increases, the five available spillway gates reached a maximum opening of 34 feet at 1700 hours. The corresponding discharge at this gate setting was estimated to be 212,260 cfs. Once the headwater elevation exceeded 450 and the gate opening exceeded 25 feet, the spillway gate rating tables were no longer applicable. To address this issue during the event, LRN water managers performed an analysis and provided the Old Hickory Power Plant operators with updated rating tables to cover the full range of use. The maximum gate opening for Old Hickory is 42 feet.
- If an even more aggressive spillway discharge pattern had been followed in order to keep the pool below elevation 450, much larger releases from Old Hickory would have been required. These higher flows would have been in the river in the Nashville area at the same time as the peak local runoff. This would have resulted in a more aggressive rate of rise and pushed the river to flood stage much sooner (several hours) in the Nashville area resulting in very limited warning time for homes and businesses.
- The Old Hickory spillway gate change implemented at 1000 hours resulted in a total project discharge of 90,000 cfs. At this time, instead of stopping all discharge from J. Percy Priest as detailed in the water control manual, the decision was made to reserve the remaining storage available in J. Percy Priest for when the flood crest approached Nashville. Given the existing hydrologic conditions, LRN water managers knew that the crest was still many hours away, and that the storage in J. Percy Priest would be much more valuable later in the event.

1000 hours – Given the regional nature of this event and ambient conditions on the Lower Ohio River, LRD WM had already assumed control of the releases from Barkley and Kentucky. Through a series of discussions between Corps' and TVA water managers, a plan was developed that resulted in a series of spillway gate increases being started at 1000 hours.

- The Barkley Water Control Manual limits spillway gate increases to 5,000 cfs/hr and no more than 40,000 cfs in one day. Given the magnitude of this event and the corresponding water control measures, it was clear that this event could not be properly managed within the guidelines of the water control manual. By midnight on 2 May, the discharge had been increased by 114,400 cfs to 156,500 cfs and several of the increases were on the order of 10,000 cfs/hr. This was done to preserve flood storage in the Barkley and Kentucky pools for later in the event. This plan also addressed a flood crest moving down the Ohio River from rainfall that had occurred several days earlier in the Ohio Basin.

2100 hours –Generation at J. Percy Priest was stopped and the first spillway gate reduction at Old Hickory was made. These actions were taken to manage the flood crest at Nashville that was forecast at the time to occur at 0100 hours on May 3.

- The reduction at J. Percy Priest was based on the travel time from J. Percy Priest Dam to the Nashville area. It was timed to reduce the flood crest through Nashville.
- A series of spillway gate reductions were implemented at Old Hickory starting at 2100 hours. Again, this was designed to reduce the flood crest through Nashville. These cuts were initiated when the Old Hickory lake level was still above the top of the surcharge pool. This is best characterized as an extraordinary measure to attempt to utilize every bit of possible storage in an effort to protect Nashville. Close attention was paid to the lake level in Old Hickory to avoid a lake level greater than the previous crest. By midnight, Old Hickory releases had been reduced from a peak of 212,260 cfs down to 193,400 cfs. Although this operation was outside the guidelines in the water control manual, if the manual would have been strictly followed, more water would have been put onto Nashville by evacuating surcharge storage from Old Hickory. Figure 1 above also covers this water control action. As noted in this plot the stage hydrograph for Nashville would have been somewhat higher for the water control manual operation than for the water control operations that were carried out during the event. However, for the last several hours on Sunday and the early morning hours on Monday the differences are fairly small.
- A total of nineteen spillway gate increases and three decreases were made at Old Hickory on May 2.

2100 hours, 2200 hours – LRN coordinated operations at Center Hill and Cordell Hull to provide flood control benefits for Carthage, TN. Hydropower generation at Center Hill was stopped at 2100 hours in anticipation of Cordell Hull discharges being increased above the control flow limit of 72,000 cfs at Carthage. At 2200 hours, following heavy rainfall in the Cordell Hull Watershed, a series of spillway gate increases were required to manage the Cordell Hull Lake level.

- Since control flow at Carthage could not be maintained while holding the Cordell Hull headwater elevation within the power pool, the water control manual states that the surcharge storage is to be utilized. Until 1500 hours, the Cordell pool was holding steady at control flow while utilizing only 1 foot of surcharge storage. Once the rain arrived in the Cordell Hull basin, it continued to be intense and slow moving. The water control manual states that if the headwater is rising faster than 0.15 feet per hour, Cordell Hull releases are to be increased and the Carthage control flow may be exceeded, but the increase is limited to 5,000 cfs per hour until the surcharge storage is used. It quickly became apparent that the Cordell Hull Lake level could not be properly managed by adhering to this requirement. Project releases were managed in as controlled a method as possible. However, spillway discharge increases as frequently as every 30 minutes and some by as much as 10,000 cfs were necessary to prevent the upstream lock gate from being overtopped. Since the water control manual states that once the top of the surcharge pool, elevation 508, is reached, then the discharge is increased as necessary at that time to maintain the water surface at that level. By allowing it to go slightly higher and increasing faster, control of the structure was maintained and sudden, significantly higher discharges were avoided, thus reducing flood impacts downstream. As noted in Figure 2 the differences in stage and flow at Carthage between the two operational

scenarios evaluated with the calibrated HEC-RAS model, actual operations and water control manual operations, are not significant. This can be attributed to how quickly the Cordell Hull Lake level responded to uncontrolled runoff from the 1,372 mi^2 local drainage area above Cordell Hull Dam. The timing and magnitude of spillway gate openings was quite consistent between the two scenarios.

- The water control actions at Cordell Hull that began late on May 2 continued through the night.
- A total of seven spillway gate increases were made at Cordell Hull on May 2.

2300 hours, 2400 hours - Hydropower generation at Dale Hollow was stopped at 2300 hours. Hydropower generation at Wolf Creek was first reduced at 2300 hours and subsequently stopped at 2400 hours. These actions were taken in accordance with the system flood control operation to store water to reduce flows downstream during the crest.

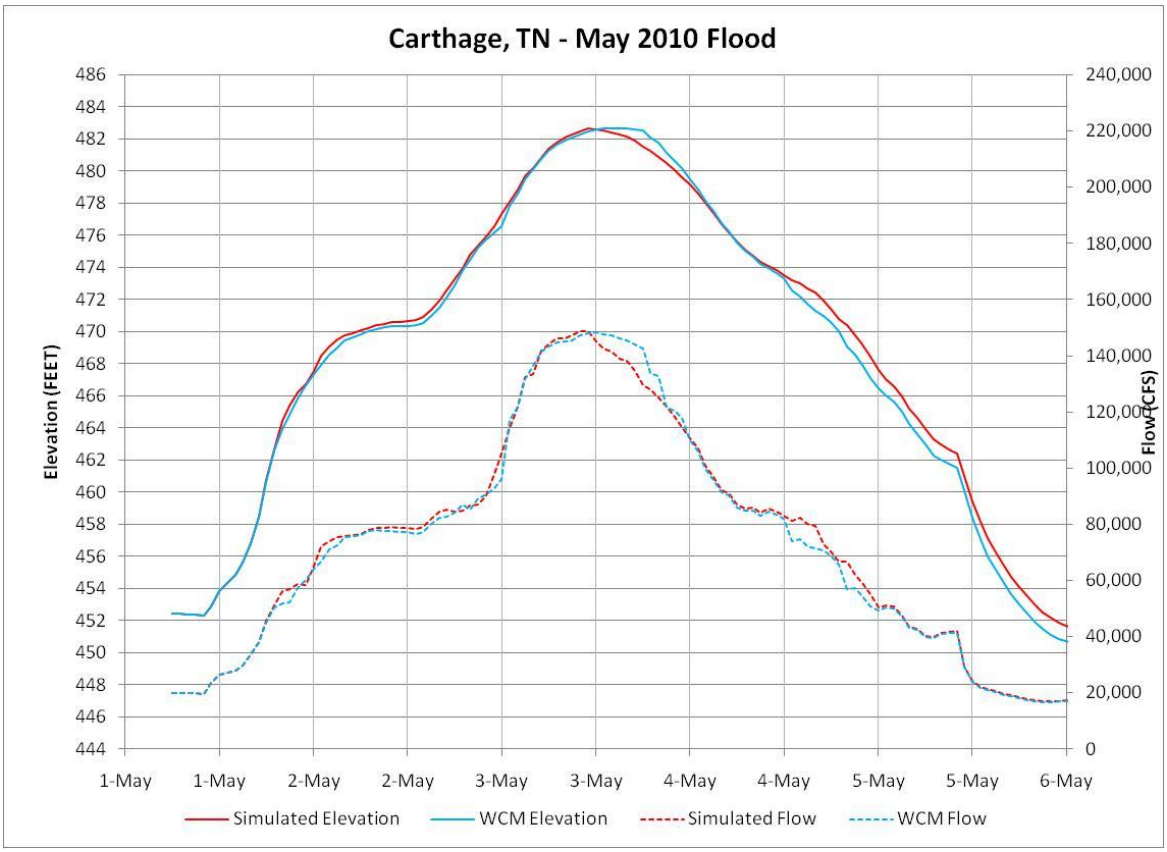

Figure 2 - Comparison of Stage Hydrographs and Flow Rates for Simulated Operations and Water Control Manual Operations at Carthage

3 May 2010: Monday

0000 hours - 0615 hours - Old Hickory makes additional spillway gate reductions at 0000 hours and 0100 hours; however, by 0300 hours the inflows to Old Hickory originating from large discharges at Cordell Hull and local uncontrolled runoff had pushed the Old Hickory pool up to

elevation 451.25. In order to slow the rise in the Old Hickory lake level, spillway gate increases were necessary at 0300 hours, 0400 hours, and again at 0615 hours.

- Collectively, these three gate openings increased the Old Hickory discharge by about 15,000 cfs to a total of approximately 197,000 cfs. This release setting was held steady until 1300 hours when a series of reductions were initiated. This action recovered a small volume of storage at Old Hickory that could be applied later when the crest approached Nashville.

0000 hours -0500 hours – Cordell Hull continued to make spillway gate increases as the lake level responded to local uncontrolled runoff. The maximum gate opening of 16 feet for this event was reached at 0450 hours. Soon after reaching this maximum gate opening the Cordell Hull lake level started to decrease. The discharge was held constant until the pool fell to elevation 507.80.

- Despite the series of spillway gate increases that had started the previous day to match the rise in inflows, Cordell Hull reached a new pool of record of elevation 508.33 at 0500 hours. At this elevation, Cordell Hull was only 2.0 inches from overtopping the upstream lock gate.

0600 hours – A flood crest of 37.62 is observed at the Celina gage.

0715 hours – The J. Percy Priest hydropower unit was brought back online.

- The J. Percy Priest headwater elevation was forecasted to go above 504.5 in the next several hours. When the lake level reaches elevation 504.5 the spillway gates have to be operated to prevent overtopping the gates. LRN water managers made the decision to bring hydropower generation back online and preserve the remaining storage in J. Percy Priest for the crest that appeared to be several hours from reaching Nashville.

1100 hours – Cordell Hull pool level drops below the elevation 508.0 surcharge storage threshold, allowing spillway gate reductions to be made. Flow reductions were made in an effort to protect Carthage, TN; the damage center located a short distance downstream of Cordell Hull Dam.

- LRN water managers issued the instruction to the Cordell Hull operators to continue to make spillway gate reductions in an aggressive fashion as long as they could do so without causing the pool level to go back above elevation 508.0.
- The Cordell Hull Water Control Manual states once the lake elevation peaks within the surcharge storage pool that the maximum discharge reached should be maintained until the headwater level recedes back to the top of the power pool (elevation 504.5).
- A total of 11 spillway gate reductions were made between 1100 hours and 2300 hours on May 3 as the project inflows continued to fall throughout the day.
- A total of six spillway gate increases and eleven decreases were made at Cordell Hull on May 3.

1200 hours – Initiated spillway gate increases at Barkley.

- LRD WM was directing operations at Barkley and Kentucky Dams. Earlier in the day the Barkley discharge had been increased to 260,000 cfs and then held steady for three hours. At 1200 hours, a series of four 10,000 cfs/hr spillway gate increases were initiated to take the total release to 300,000 cfs. These 10,000 cfs/hr increases exceeded the maximum guideline of 5,000 cfs/hr identified in the Barkley Water Control Manual. The 300,000 cfs flow represented a new record discharge for the Barkley project.

- This action was taken to conserve storage in the Barkley and Kentucky pools for a flood crest that was coming down the Ohio River.
- When these flow increases were made the Barkley tailwater rose accordingly, resulting in the flooding of several homes downstream of the dam.
- The Barkley Water Control Manual does not address notification of downstream interests when significant flow increases are made. The practice has always been that LRN WM contacts the Barkley Power Plant operator and issues instructions on how and when spillway gate changes are to be made. In turn, the operator alerts both Barkley Lock and Lock &Dam (L&D) 52 of the upcoming change. Ultimately, the Barkley Resource Manager's Office typically coordinates with local emergency management offices on flow increases; however, this procedure is not a formalized process. The Barkley Resource Manager is very familiar with the river and will call if they sense a change. LRN will develop a formalized plan to alert downstream emergency managers (in addition to the ongoing process through the NWS) similar to what is in place with the lock for timely communication of changes in discharge.

1200 hours – A flood crest of 46.06 is observed at the Carthage gage.

1300 hours - Spillway reductions are initiated at Old Hickory in an effort to reduce the flood crest through Nashville. There was a particular emphasis placed on preventing inundation of Nashville's Omohundro Water Treatment Plant due to the fact that the other Nashville water treatment plant (K. R. Harrington located at the mouth of the Stones River) had been flooded earlier in the event. Thanks to the intensive sand bagging efforts, using sandbags furnished by LRN, the City of Nashville was able to prevent the loss of their potable water supply.

- Between 1300 hours and 1730 hours a total of spillway gate reductions were made at Old Hickory. These reductions reduced the flow out of Old Hickory from 196,500 cfs at 1300 hours to 144,200 cfs at 1900 hours, or a total flow reduction of around 52,000 cfs.
- The Old Hickory Lake level was closely monitored by Project and Water Management personnel during and following these flow reductions. The pool was allowed to rise back above the top of the surcharge storage pool. This prevented additional water from being placed on top of the crest as it entered the Nashville area. A break in weather conditions provided an opportunity for this action to be taken. The rain had ended and significant flow reductions had been made at the upstream projects as the flood crest had already moved through.
- The Old Hickory Water Control Manual states once the lake elevation peaks within the surcharge storage pool that the maximum discharge reached should be maintained until the headwater level recedes back to the top of the power pool (elevation 445.0).
- A total of three spillway gate increases and eight decreases were made at Old Hickory on May 3. No additional spillway gate changes were required until Wednesday, May 5.

1500 hours – A special request was made by TVA to address a power transmission line problem associated with Dale Hollow being off-line. The remedy for this problem was to bring one hydropower unit back online. LRN WM reviewed the request, and determined that since Celina had crested and local flows were receding, this could be done without any downstream impacts. One turbine was placed in service at 1500 hours.

- This action was consistent with guidance in water control manuals with respect to recovering flood control storage after the flood crest has passed.

1800 hours – A flood crest of 51.86 is observed at the Nashville gage.

1900 hours - Spillway reductions initiated at Barkley in response to downstream flooding.

- Two spillway gate reductions were made to reduce the Barkley outflow to around 280,000 cfs. This was done in response to flooding of several homes in an area a short distance downstream of Barkley Dam. This flow was maintained through the end of the day.

2200 hours – Cheatham reaches a new pool of record of elevation 404.15.

2330 hours – LRN performed surcharge operation at J. Percy Priest.

- Old Hickory Hydropower personnel were dispatched to J. Percy Priest Dam to carry out a surcharge storage operation. They were instructed to continuously track the J. Percy Priest Lake elevation and when the pool reached the top of gates they were to open each of the gates 0.5 foot. This was done to limit releases as much as possible to prevent an increase in water levels above the observed crest.
- The J. Percy Priest spillway gates were initially opened at 2330 hours. However, one of the gates did not function properly. The field staff opened one of the gates to 1.0 foot and two gates to 0.5 ft. An Old Hickory Power Plant electrician was called in. He quickly diagnosed the problem with the gate and made the necessary repair. This quick action prevented the non-functioning gate from being overtopped. At 2400 hours all four gates were opened to 0.5 foot. This resulted in a project release of 7,000 cfs.
- With the J. Percy Priest headwater elevation at 504.5, the water control manual specifies a total project release of 17,000 cfs. This is generally considered to be the channel capacity for the Stones River below J. Percy Priest. However, given how high the Cumberland River was at the time, a release of 17,000 cfs would have induced additional flooding along the Stones River and would have likely increased the Nashville stage higher than the earlier crest. The HEC-RAS model results for the Nashville gage presented in Figure 1 are somewhat inconclusive in that the stage difference observed at Nashville cannot be specifically tied to flow reductions at Old Hickory or delaying spillway operations at J. Percy Priest. Rather, for the period starting Monday (May 3) evening and extending through the middle of the day on Wednesday (May 5), the combination of water control actions executed by LRN water managers at these two projects resulted in significant stage reductions (~ 2 feet for much of this period) at Nashville when compared to the water control manual operational scenario modeled with HEC-RAS.

4 May 2010: Tuesday

0000 hours – Two hydropower units were brought online at Wolf Creek and one at Center Hill. A third Wolf Creek unit was brought online at 1200 hours.

- This is in accordance with the water control manuals that state, "After the flood crest has passed, utilized flood control storage is evacuated as fast as practical to prepare for future potential floods."

0000 hours - 0500 hours – Spillway gate reductions at Cordell Hull.

- As the Cordell Hull local runoff receded, a series of spillway gate reductions were made to reach control flow (0500 hours). LRN WM instructed Cordell Hull to hold control flow until the pool fell to within two feet of guide curve (1600 hours). At that point a spillway gate cut scheme was developed to allow a smooth transition to normal operating levels.

- All gates at Cordell Hull were closed at 0600 hours on the next day.

0400 hours -1600 hours – Submergence problems with the spillway gates at Barkley.

- When the Barkley project experiences extremely high tailwater elevations like it did on this date a submergence problem is encountered with operation of the spillway gates. The Barkley spillway gates must be clear of the water on the tailwater side when in operation or they will be subject to extreme vibration. Therefore, a gate must be either closed or open high enough to clear the tailwater. As a result, operators and water managers are sometimes unable to produce the desired flow and must decide on either a flow lower than the target or higher. The differences can be fairly significant since extremely large gate openings are required at the individual gates.
- The Barkley Power Plant operators were forced to make a series of gate changes between 0500 hours and 0805 hours to address submergence problems. During high discharges from Barkley Dam, when the tailwater elevation becomes high, the spillway gates can become partially submerged. This results in intense vibration that threatens the structural integrity of the spillway section. Therefore, adjustments to the gate arrangement must be made quickly to alleviate this situation. The solution to this problem requires that individual gates are either raised to very large gate openings or they remain closed. As a result, rather than opening many or all gates to a moderate gate opening, a few gates are opened to very large gate openings. The final result is that project outflows are often either higher or lower than the target release due to the limitations on spillway gate use. During this period the spillway gate settings resulted in project releases that were higher than the objective.
- Barkley set a new discharge record of 303,200 cfs at 0800 hours.
- At 0800 hours per direction from LRD WM, LRN WM directed Barkley to reduce project discharge to 240,000 cfs. Again, due to submergence the closest the operators could get to this target was 266,000 cfs by completely closing one gate.
- At 1600 hours per direction from LRD WM, LRN WM directed Barkley to close one additional spillway gate. This resulted in a project discharge of 230,000 cfs.

0700 hours – A flood crest of 62.58 feet is observed at the Clarksville gage.

0800 hours – Spillway gate adjustment at J. Percy Priest.

- A surcharge operation at J. Percy Priest had been initiated at 2330 hours the previous day. By 0800 hours the lake level had risen to the point that a gate adjustment was required to prevent overtopping the gates. The gates were raised an additional 0.3 foot each to prevent water from spilling over the gates. This increased the project release from 7,000 cfs to 8,600 cfs.

5 May 2010: Wednesday

0600 hours – All spillway gates at Cordell Hull were closed and the project was returned to normal operations.

0900 hours – A series of spillway gate reductions were initiated at Old Hickory as the inflow to the project steadily declined.

- A total of ten spillway gate reductions were made at Old Hickory on May 5.

1200 hours – Additional hydropower units were brought online at Wolf Creek, Dale Hollow, and Center Hill as the effort to recover reservoir storage continued.

- Wolf Creek – went from three units to five units at 1200 hours

- Dale Hollow – went from one to two units at 1200 hours
- Center Hill – went from one to two units at 1200 hours and from two to three units at 1400 hours.

6 May 2010: Thursday
0000 hours -1300 hours – Spillway gate reductions at Old Hickory continued throughout the day. Old Hickory was back within its normal operating range by the end of the day.
1000 hours – Continued to adjust project release schedules at the tributary projects to evacuate water from storage.
- Wolf Creek – opened two sluice gates at 1000 hours
- Center Hill – opened two sluice gates at 1230 hours

1000 hours – Ohio River Flood Control Operation
- Initiated a series of spillway gate reductions to reach a total flow of 150,000 cfs by 1900 hours. This was directed by LRD WM to support ongoing flood control operations for the Lower Ohio River.

7 May 2010: Friday
0000- hours 2400 hours – No significant water management actions were required.
- Cordell Hull and Old Hickory had already returned to normal operating levels.
- The process of evacuating water from storage continued at Wolf Creek, Dale Hollow, Center Hill, and J. Percy Priest.
- Cheatham remained in free flow as it had been since Saturday, May 1 at 1900 hours.
- Releases at Barkley continued to follow the requirements of the ongoing Ohio River flood control operation.

1600 – Barkley reached a peak elevation for this event of 369.00. This is about 1.0 ft lower than the pool of record established during the May 1984 flood event.

8 May 2010: Saturday
0830 hours – The spillway gates were placed back in service at Cheatham. This action returned Cheatham to normal project operations.
1000 hours – Continued to adjust project release schedules at the tributary projects to evacuate water from storage.
- J. Percy Priest – increased spillway discharge by 1,000 cfs to a new total discharge of 9,100 cfs at 1000 hours
- J. Percy Priest – increased spillway discharge by an additional 1,000 cfs at 1100 hours. The revised total project discharge was now 10,100 cfs.

1000 hours -1200 hours – Reduced project discharge from 150,000 cfs to 120,000 cfs by applying three 10,000 cfs reductions.
- The 120,000 cfs discharge at Barkley was continued until May 17 when flows were further reduced to 70,000 cfs. On May 18 the flows were reduced again to 50,000 cfs.

Why did it happen?
-The Cumberland Basin was subjected to an epic rainfall and a flash flood event that started on May 1, 2010. A significant amount of the intense rain fell over the uncontrolled portion of the

basin adjacent to the Cordell Hull, Old Hickory, and Cheatham projects. The two-day rainfall totals were in excess of 15 inches in many areas, and exceeded the 1,000-year rainfall event.
-This event generally outpaced the science in terms of being able to develop accurate, timely rainfall forecasts, model the hydrology, and develop well-timed flood crest forecasts.
-The event also outpaced the capability of the Cumberland Basin reservoir system to manage the event in a prescribed manner.
-The notification process for flow increases at Barkley, which in the past had worked adequately during moderate storm events, did not hold up to the rigors of a major flood.
-The network outage that occurred on Sunday, May 2 limited LRN WM's access to data during a critical period. The only access to this data was via internet service on personal cell phones and by calling the projects.
-Rating tables for spillway gates at Old Hickory were not extensive enough to cover the full range of gate openings required during the event.
-The water control manuals do not include slope storage tables for Cordell Hull, Old Hickory, and Cheatham. This made developing reasonable estimates of project inflows during the event problematic when slopes on individual projects of approximately 35 feet were observed.
-The current water control manuals for the Cumberland River Basin projects were last updated in 1998. The 1998 revisions were updates of manuals prepared when the projects were constructed, which for several was in the 1950s. For some of the newer projects, the 1998 manuals were the first manuals developed.

How can we do it better and who has the lead to fix it?
-LRN will develop a notification process in the water control plans for the projects to pass critical information to emergency managers in a timely manner with clear roles and responsibilities defined. The process should include notification of the Resource Managers.
-LRN WM will update the project water control manuals to cover more extreme events and will include updated rating curves and slope storage tables for the main river projects.
-LRN WM will investigate issues within the water control manuals that were not robust enough to deal with the magnitude of this flood event. Those issues required LRN water managers to deviate from guidance in the manuals in order to reduce flood impacts at particular locations.
Cordell Hull.

- The hourly rate of change limit of 5,000 cfs/hr was not sufficient to manage the project inflows during this event. LRN is evaluating raising the allowable increase to better position the project to manage surcharge storage without imposing sudden flow increases on Carthage.
- The current water control manual states that once the surcharge storage upper limit of elevation 508.0 is reached, a one step flow increase large enough to pass inflow (and prevent any further pool rise) should be implemented. A sudden discharge increase of the magnitude necessary for extreme flow events would result in a rapid rise downstream, including the Carthage damage center.
- The water control manual states that the maximum discharge should be maintained until the Cordell Hull Lake level gets back to near normal operating range. This operational scheme runs the risk of putting the maximum discharge on the crest when flows could be reduced by employing available surcharge storage.

Old Hickory

- The hourly rate of change limit of 5,000 cfs/hr was not sufficient to manage the project inflows during this event. LRN is evaluating raising the allowable increase to better position the project to manage surcharge storage without imposing sudden flow increases on downstream areas including Pennington Bend and Nashville.
- Existing guidance in the water control manual correlates discharge increases to prescribed rates of rise in the surcharge storage pool. This policy does not always support utilization of available surcharge storage at the most opportune time to maximize downstream flood risk management benefits. LRN will evaluate and update the water control manual.
- The current water control manual states that once the surcharge storage upper limit of elevation 450.0 is reached, a one step flow increase large enough to pass inflow (and prevent any further pool rise) should be implemented. A sudden discharge increase of the magnitude necessary for extreme flow events would result in a rapid rise downstream including the Nashville damage center. LRN will evaluate and update the water control manual.
- The water control manual states that the maximum discharge should be maintained until the Old Hickory Lake level gets back to near normal operating range. This operational scheme runs the risk of putting the maximum discharge on the crest when flows could be reduced by employing available surcharge storage. Need to evaluate and update the water control manual.

J. Percy Priest

- The J. Percy Priest water control manual states "If the Nashville flow is forecasted to exceed the maximum desired level, releases from J. Percy Priest are curtailed, and flood control storage utilized in a manner that will reduce the flood crest at Nashville as much as practical." Under scenarios like the May 2010 flood event, this requirement forces flood storage to be used early in an event rather than save it for use at the time of the crest.
- Existing guidance for operation of J. Percy Priest using the Emergency Operations Schedule in the water control manual does not accommodate (under all flood related scenarios) reducing the discharge from the project at critical times as flood crests approach Nashville. This flood control project provides the last opportunity to reduce the flood crest at the Nashville damage center. However, when the lake level is within the surcharge pool (greater than elevation 504.5) the Emergency Operations Schedule requires a minimum of 17,000 cfs being released from the project. This goes against the effort to utilize all available flood control in an effort to reduce downstream flood damages.
- The Emergency Operations Schedule requires that if the rate of rise in the headwater at specific headwater ranges reaches (both above and below elevation 504.5) a prescribed amount, then the pre-determined releases should be made. For the May 2010 event, this requirement would have resulted in a spillway gate increase of approximately 11,000 cfs over what was observed. Given the timing of when this guidance would have applied, the additional water would have increased the flood crest in Nashville.

Barkley

- The hourly rate of change limit of 5,000 cfs/hr and the corresponding 40,000 cfs daily discharge increase were not sufficient to manage the project inflows during this event.

LRN will evaluate raising the allowable discharge increase, both the hourly rate of rise and the daily limit, to better position the project to manage flood control storage in support of flood control operations for the Ohio and Mississippi Rivers.